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ASSESSMENT AND FISHERIES MANAGEMENT OF EASTERN BERING SEA WALLEYE POLLOCK: IS SUSTAINABILITY LUCK?

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ABSTRACT

Alaska pollock is the largest component of white-fish production worldwide representing about 45% of all white fish. The portion of pollock caught within U.S. waters has been stable, averaging around 1.2 million t over the last two decades. The condition of the eastern Bering Sea (EBS) pollock stock in 2001 appears to be quite healthy with biomass levels estimated to be around 10 million t. These estimates have a relatively large degree of uncertainty, even though fishery monitoring and survey efforts for this stock are extensive. Part of this uncertainty can be attributed to variable stock dynamics, including spatial variability due to environmental conditions and demographic variability such as pre-recruit survival, natural mortality, and growth. At some point, improving observations on current stock conditions give diminishing returns on improving forecast abundance. Long-term projections illustrate that, given the level of observed recruitment variability, stock biomass levels can vary quite widely, even under little or no fishing. So, how has the pollock fishery become sustainable? In part, early decisions to closely regulate fishing (using truly effective quotas and hence effort rationalization) have led to a successful and so far, sustainable fishery. In addition, an overall cap on total groundfish removals (2 million mt) from the EBS ecosystem has limited individual stock quotas and hence led to a stabilized fishery well within the bounds of sound conservation principals. The combination of effective management regimes together with a rationally developed fishery appear to be ideal for sustaining the Alaskan pollock resource and fisheries.

Alaska pollock *Theragra chalcogramma* (Pallas, 1814) are concentrated in the Bering Sea and are broadly distributed in the temperate waters of the north Pacific. By weight, pollock represent the largest single-species landings of all fisheries in the U.S. (NMFS, 1999). A number of different markets currently exist for pollock. Slightly less than half of the production is marketed within the U.S. in product form as fillets and surimi (a minced and processed product). These forms are supplied to restaurant chains and food processors to develop value-added products (e.g., frozen battered fillets, fish sticks, and imitation crab legs). About 5% of pollock is marketed in Europe, and slightly less than half of the total U.S. production is sold to Asian markets (primarily Japan). In addition to these products, pollock roe is marketed in Asia and represents about 30%–40% of the annual catch focused on roe production. The total U.S. North Pacific groundfish catch value after primary processing was approximately US$1.3 billion with about 61% or US$800 million of that attributed to the pollock catch in 2000 (Hiatt et al., 2001). The pollock fishery represents an important fishery and interest in the sustainable management of this resource is given a very high priority.

The stock structure of pollock is poorly understood. This species appears to maintain distinct spawning areas that are consistently inhabited each year. However, the degree of mixing among distinct stocks is poorly understood during other seasons. Bailey et al. (1999) present a comprehensive review of the pollock stock structure and note that this species is fairly adaptive and inhabits a variety of areas. For the eastern

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Bering Sea (EBS), the primary spawning apparently occurs during January–May in the southern portion extending from Unimak Island to the Pribilof Islands. Based on the volume of pollock biomass found in this region, this is considered the primary source of subsequent recruitment. In this paper, aspects of the current EBS pollock fishery are highlighted and conservation and management measures used for the North Pacific groundfish are explained. Since the conservation measures used for Alaska pollock are based on scientific data collection analyses, a description of the stock assessment methods and data used to derive sustainable catch is provided (this section draws heavily from Ianelli et al., 2001). Finally, given that the pollock resource can vary substantially due to recruitment variability, some perspective on the prospects of maintaining target conservation or biomass reference levels are presented.

Fisheries and Stock Assessment

Fishery Characteristics.—From 1954–1963, pollock were harvested at low levels, particularly in the EBS. Directed foreign fisheries began in 1964 and Bering Sea-wide catches increased rapidly and peaked in 1970–75 when annual catches ranged between 3 and 9 million t. After the peak catch of 9 million t in 1972, catches were reduced through bilateral agreements with Japan and the USSR. Production of pollock from the Sea of Okhotsk and in the western Bering Sea has been higher than in the U.S. EEZ for the last two decades. However, there are indications that some stocks in these regions are approaching low levels and recent catches reflect this drop (Fig. 1). Nonetheless, pollock catch levels continue to represent a substantial amount of the world white-fish market production (Fig. 2).

Since the advent of the U.S. EEZ in 1977 the annual average EBS pollock catch has been 1.1 million t, ranging from 0.9 million in 1987 to nearly 1.5 million t in 1990, while stock biomass has ranged from a low of 4–5 million to highs of 10–12 million t. In 1980, U.S. vessels began fishing for pollock and by 1987 they were able to take 99% of the quota. As of 1988, only U.S. vessels have been operating in this fishery and by 1991 the current domestic observer program was fully operational.

The seasonal pattern of the fishery since the late 1980s has traditionally been a winter season beginning on January 20th and lasting about 6 wks followed by a late summer to early fall fishery (August–November). The timing and duration has changed somewhat in recent years due to the American Fisheries Act (see below) and other management measures designed to minimize the potential impact the pollock fishery may have on the recovery of the Steller sea lion population. Depending on ice conditions and fish distribution, the winter fishery effort is typically north of Unimak Island and along the 100 m contour between Unimak Island and the Pribilof Islands; whereas the late summer fishery extends much farther into the northwestern part of the shelf area (Fig. 3). The length frequency information from the fishery for these seasons indicate that pollock are generally larger than 40 cm but with some smaller fish caught during years when a strong year-class appeared, especially during the late summer fishery (Fig. 4). These length frequency data also shows the marked progression of the large 1989 year-class growing over time and the appearance of the 1992 year-class in 1996–97 and subsequent 1996 year-class in 1998–2001.

The current EBS pollock fishery can be characterized as having a very low percentage of bycatch (closely monitored by professional observers) and minimal impact on

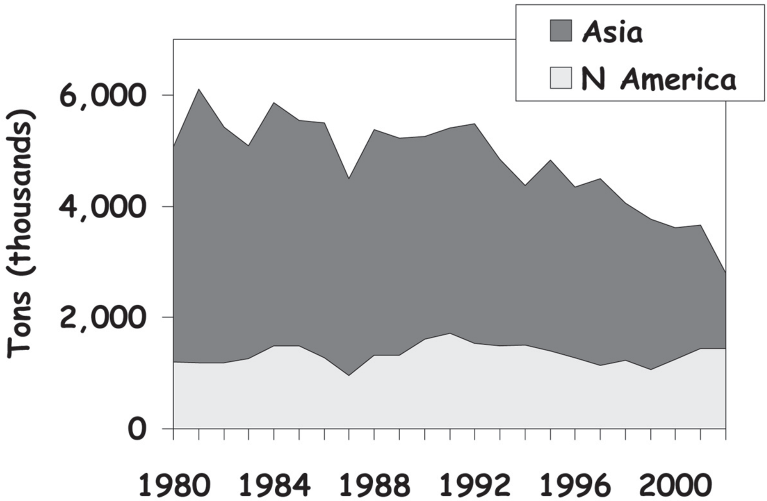

Figure 1. Estimated landings of Alaska pollock by region, 1980–2001.

habitat since only pelagic trawls are allowed. In 1999 congress passed a bill titled the American Fisheries Act (AFA) in which the number of vessels participating in the fishery were reduced and quota-sharing cooperatives began to develop. The formation of these cooperatives eliminated the "race-for-fish" aspect of the quota system. The vessels under the cooperative system receive a portion of the overall quota. This gives participants an increased flexibility in where and when they could fish. An ongoing pollock fishery issue is the incidental harvest of prohibited species (e.g., salmon, herring, crab, and Pacific halibut). Since these bycatch levels are managed (the fleet must remain below given allowable levels of incidental catch), the industry participants themselves promote methods that reduce bycatch. This has been done largely

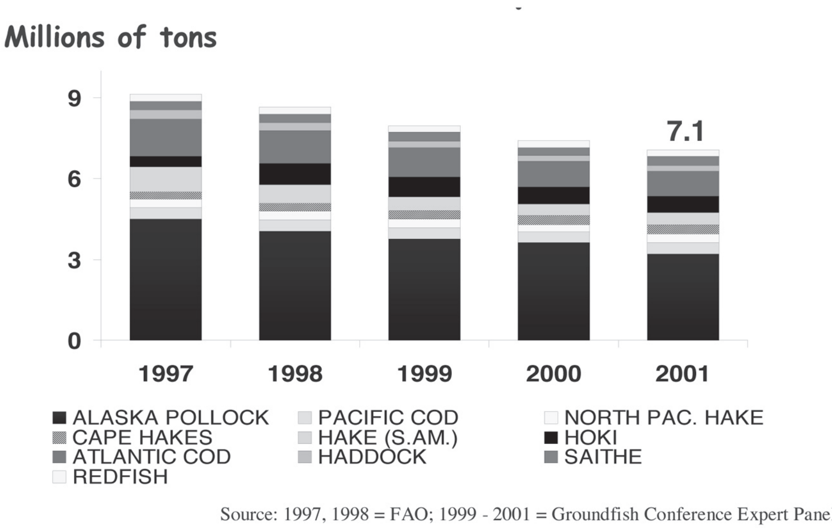

Figure 2. World estimated landings of major groundfish species, 1997–2001.

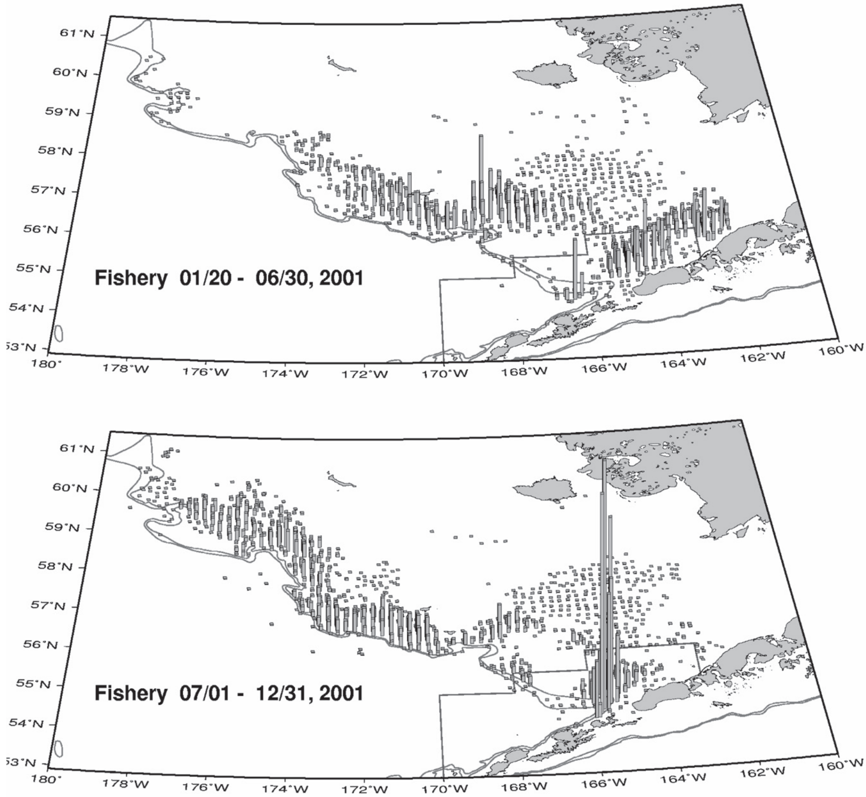

Figure 3. Concentrations of pollock catch fishery in 2001, January–June (top panel) and July–December (bottom panel) on the Eastern Bering Sea shelf.

by coordinating real-time information on areas where bycatch rates are higher. Another critical issue affecting the pollock fishery is the listing of the western stock of Steller sea lions on the U.S. Endangered Species list. This issue revolves around the possibility that the impact of fishing, even at conservative levels, has impeded the recovery of this group of animals (estimated to number about 32,000 individuals in 2001). The impact of the fishery has been argued to be one of resource proximity; i.e., that the Steller sea lions required range of foraging has increased and contributed to added stress. To minimize these impacts, NMFS has closed pollock fishing in large areas (including the Aleutian Islands region) considered critical to Steller sea lion foraging. The degree of interaction between depleted resources (such as Steller sea lions) and fisheries that focus on prey items for these same resources presents an added management challenge.

Stock Assessment Analyses

Surveys.—The Alaska Fisheries Science Center (AFSC) has conducted annual summertime bottom-trawl surveys since 1982. These surveys are designed to assess the abundance of crab and groundfish in the EBS. Since Alaska pollock are commonly found off-bottom, this survey is considered to sample only a portion of the popula-

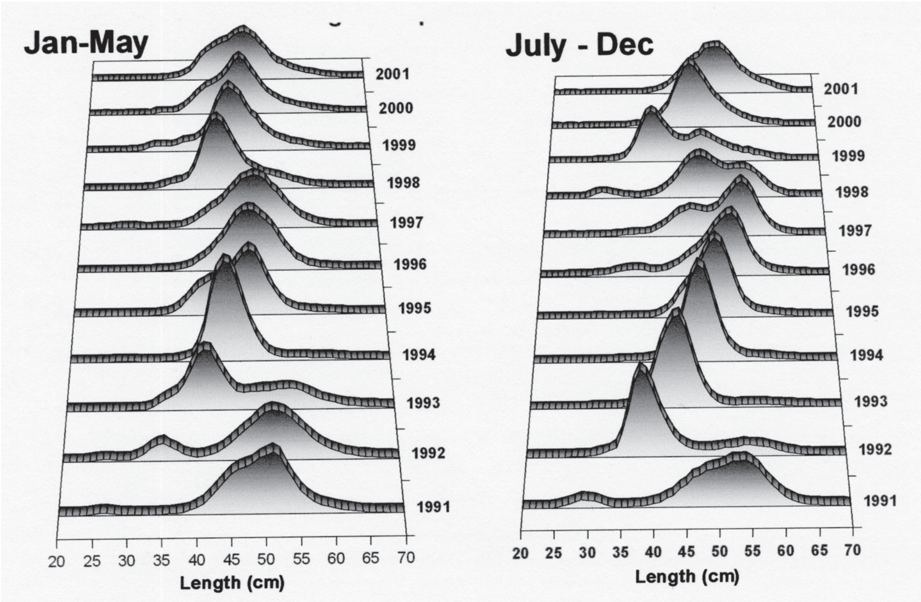

Figure 4. Length frequencies of Alaska pollock for the Eastern Bering Sea region, 1991–2001, by major season.

tion. Typically, the average age of pollock found on the bottom is older than those sampled off-bottom. Between 1991 and 2001 the bottom trawl survey biomass estimates (for the on-bottom component of the population) have ranged from 2.2–5.5 million t. In general, the survey indicates a relatively variable but stable stock trend since 1982 with periods of 3–4 yrs of increases and decreases (Fig. 5). This variability is due to the effect of year-class variability evident from survey abundance-at-age estimates. One characteristic of year-class variability from survey data is that some strong year-classes appear in the surveys over several ages (e.g., the 1989 year-class) while others appear at older ages (e.g., the 1992 year-class). This suggests that the age-specific spatial distribution of pollock available to bottom-trawl gear is variable.

Whereas bottom trawl surveys are conducted annually and assess pollock from the bottom to 3 m off bottom, echo-integration (hydroacoustic) trawl (EIT) surveys have been conducted approximately triennially since 1979 to estimate pollock abundance in midwater (Traynor and Nelson 1985). The details and research results from these EIT surveys have been presented in the main stock assessment reports (e.g., Ianelli et al., 2001). The survey results from 2001 showing typical spatial concentrations of pollock abundances are given in Figure 6.

Assessment Modeling.—An integrated statistical (Bayesian) stock assessment approach is employed for analyses of EBS pollock. The model used is an extension of the ideas proposed by Fournier and Archibald (1982) and later elaborated on by Methot (1990), McAllister and Ianelli (1997), Ianelli and Fournier (1998), and Quinn and Deriso (1999). Briefly, the model treats fishing mortality as a continuous semi-separable form (meaning there is a normalized time-varying age component in addition to the time component that relates to fishing effort). The core structure of the model represents "true" but unobservable population numbers at age based on a variety of parameter estimates. The primary observed data used to tune the model include estimates of total catch, the two survey indices (acoustic and bottom trawl),

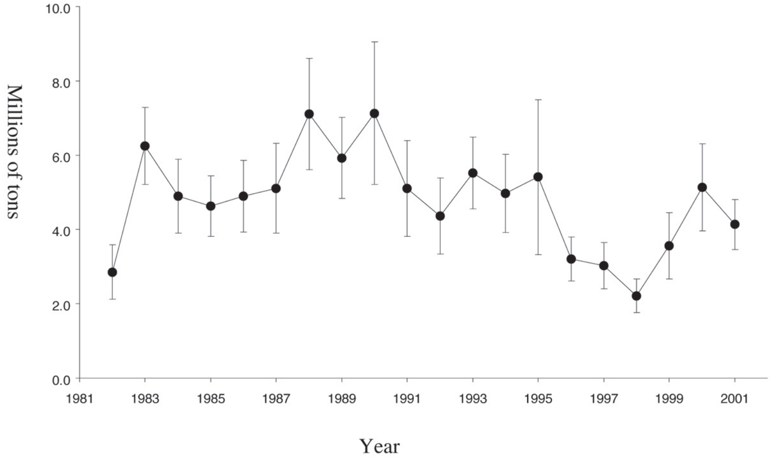

Figure 5. Alaska pollock biomass estimates from summer bottom trawl surveys, 1982–2001. Confidence bars represent two standard deviations of the estimate.

and the estimates of fishery and survey catch proportions-at-age. Parameters estimated independently (outside of the model) include mean weights-at-age and -year, maturity-at-age, and natural mortality-at-age. Parameters estimated conditionally (within the model) number more than 700 —mostly representing the fishing mortality matrix, recruitment, and survey selectivities. For details on the model specification, see Ianelli et al. (2001). In summary, the model can be characterized as one that includes a moderate number of stochastic processes while accounting for observation errors. These are principally changes in age-specific availability over time for survey and fishery gears and recruitment variability. As specified, these processes

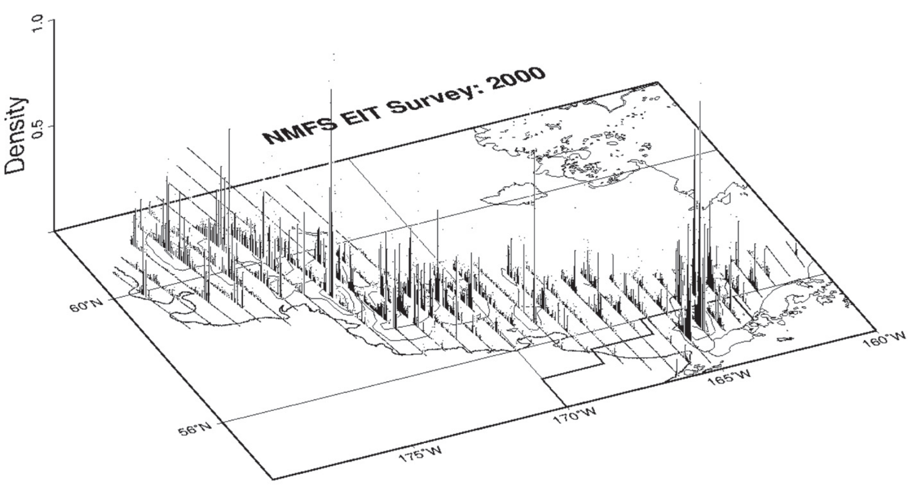

Figure 6. Distribution of Alaska pollock found in mid-water as surveyed using acoustic methods, June–July 2000. The height of the vertical columns is proportional to the relative pollock biomass observed along transects. Contours at the base of the map represent smoothed values for relative biomass density.

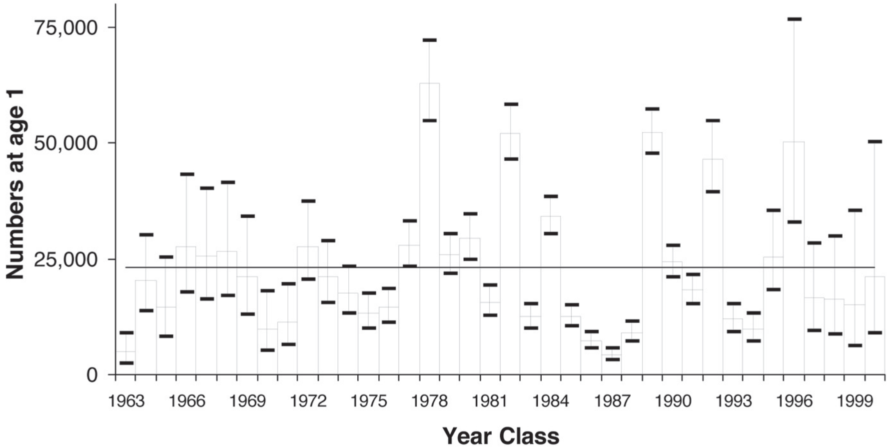

Figure 7. Assessment results for Eastern Bering Sea pollock showing inter-annual variability in year-class (in millions).

involve a large number of parameters but capture a reasonable amount of the overall uncertainty. For example, since pollock are likely to move between areas depending on age and oceanographic conditions, it seems reasonable to include a component of uncertainty related to the expected "coverage" of the standard survey area from one year to the next. An example of this type of process is detailed in the following sections.

The results from the integrated statistical model indicate that recruitment variability is substantial, and that the estimates themselves are relatively uncertain, particularly for recent years (Fig. 7). These errors propagate into the estimates of biomass (Fig. 8). While these confidence bands seem quite large given the relatively large amount of data available for this stock, a significant portion of this uncertainty pertains to the types of process-error variability (e.g., survival, environmental effects, and spatial variability relative to the survey area).

Studies on the Spatial Abundance by Area.—NMFS survey data have proved valuable to gain insights on the movement and distribution of pollock around the Bering Sea. For example, when pollock survey catch rates are compiled on a size- or age-specific basis, clear patterns over space and time emerge. Catch-rate weighted mean-length plots reveal that smaller fish are more common in the northern areas with apparent movement towards the south and east as the pollock become larger (Ianelli et al., 2001). These patterns are also revealed when one computes the centers of abundance based on age-specific CPUE data; this is done by simply computing the CPUE-weighted average location for specific ages. Since bottom temperature has long been considered important in the distribution of pollock on the shelf, years were pooled into three categories of mean bottom temperature: cold (°C < 2), intermediate (2 < °C < 3), and warm (°C ≥ 3). The average locations for warm years are farther on-shelf than for cold years (Fig. 9), indicating a broader dispersal onto the shelf in warmer years. The average locations for intermediate years were not depicted here, but were most similar to the cold years. The mean centers of distribution in both warm and cold years have very similar patterns with age. Younger fish are found to

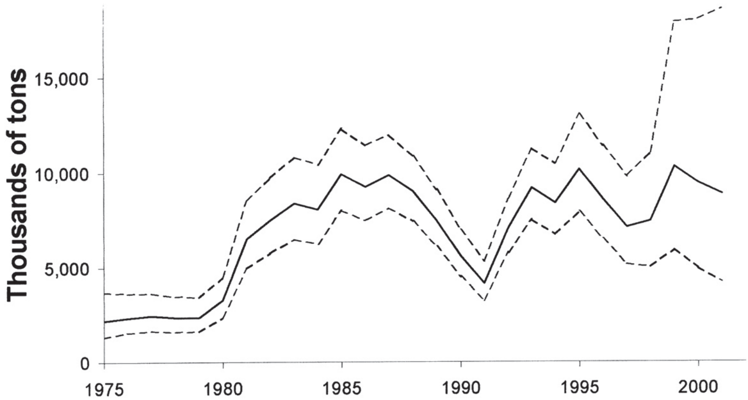

Figure 8. Assessment results for Eastern Bering Sea pollock showing mid-year age 3 and older biomass estimate with approximate 95% confidence bands.

the north and northwestern regions, and as they age, the centers of distribution move south and southeasterly.

Effect of Temperature.—Since temperature has been shown to affect the distribution of pollock on the shelf, it seems likely that temperature may affect the availability of the stock to the "standard" survey area. That is, temperature may affect the proportion of the stock that is within or outside of the standard survey area. To evaluate this effect on survey catchability a simple linear relationship was used to model annual catchability. For year t, and temperature T_t, catchability is given as:

$$q_t = m_q + b_q T_t$$

where m_q is the mean catchability and b_q represents the slope parameter.

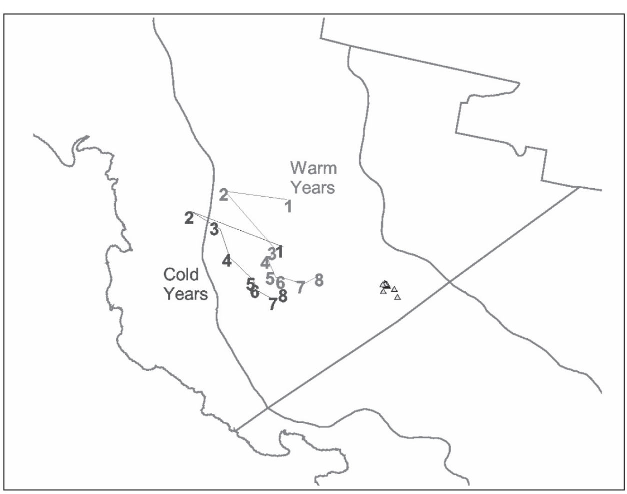

Figure 9. Eastern Bering Sea pollock weighted (by number) average location by ages 1–8, 1982–2000. Lower-left line represents the average from "cold" years while the upper right line represents average location during "warm" years (from Ianelli et al., 2001).

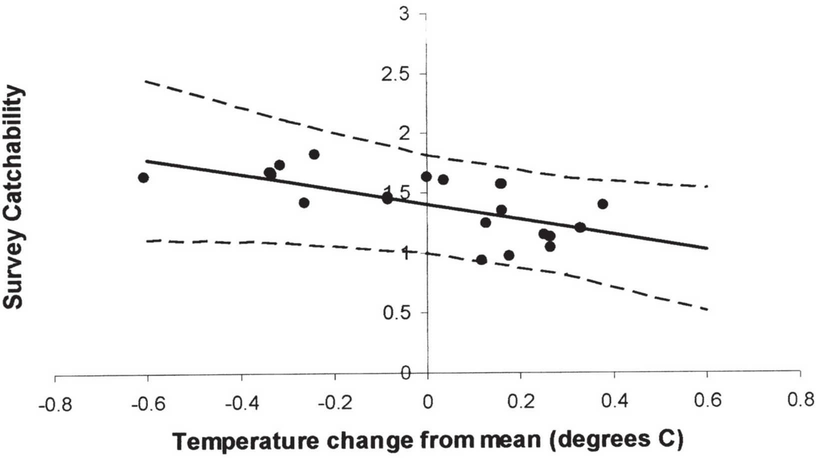

Figure 10. Estimated relationship between pollock bottom-trawl survey catchability and bottom temperature (normalized to have a mean value of 0). Points represent residuals relative to survey estimates (i.e., $\hat{q}_t + \ln(\hat{I}_t/I_t)$) where $\hat{I}_t$ and I_t represent the predicted and observed survey indices respectively and is the expected catchability given the temperature anomaly in year *t*.

Results suggest that there is a slight negative relationship between bottom temperatures and survey catchability (slope –0.63, with standard error 0.36). Based on this relationship, survey catchability tends to be lower at warmer temperatures and slightly higher at colder temperatures (Fig. 10). In other words, in cold years pollock appear to be more available to the survey gear than in warm years.

Additional research investigating the mechanism for the apparent effect of bottom temperature on survey catchability/availability is ongoing. One hypothesis is that during colder years, pollock are more prevalent on the bottom than in warm years. Alternatively, their overall distribution may be different (i.e., fall farther outside of the standard survey area during warmer years).

Conservation Measures

History.—Groundfish fisheries management since the Magnuson Fisheries Conservation and Management Act (MFCMA, 1978) has undergone a rapid evolution in the North Pacific. Since implementation of the original act, fisheries shifted from being predominantly foreign vessels to being entirely domestic with about 7 yrs of joint venture operations during the 1980s. This provided an excellent opportunity for fisheries management to proceed cautiously and deliberately. Protective measures and a strong management authority prevented excessive fleet capitalization and provided reasonable development strategy. These measures included: 1) strict quota regulations (fishery closures); 2) high levels of observer/data collection; 3) strict accounting that includes bycatch; 4) incentives to limit bycatch; and 5) an overall limit on the species-aggregated quotas.

Quota specifications leading to strict regulations are based on the best available scientific information and begin with estimates of acceptable biological catch (ABC) levels. ABC values are determined based on harvest rates that are less than the theo-

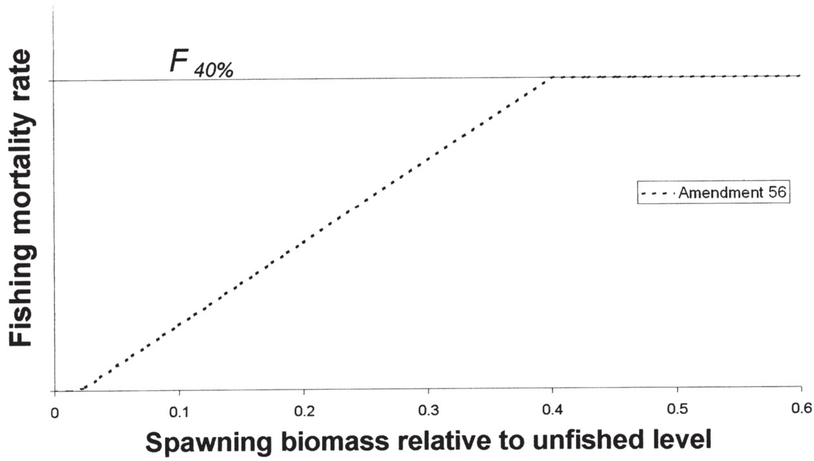

Figure 11. Typical harvest control rule for tier 3 of Amendment 56 (as used for North Pacific groundfish) compared with a constant fishing mortality rate over different proportions of unfished spawning biomass levels.

retical Maximum Sustainable Yield (MSY) harvest rate estimates. In the types of age-structured models used for North Pacific groundfish stocks computation of fishing mortality rates that achieve MSY require estimates of the stock-recruitment relationship. Because these estimates have traditionally been impractical or unreliable, a proxy fishing mortality based on the level that spawning biomass *per recruit* is reduced (relative to unfished) is used (Clark, 1991). These proxies are used to compute the overfishing level (OFL) and are designated F_{OFL}. A more conservative fishing mortality rate (depending on the current stock status and measures of uncertainty) is used to compute the analogous ABC fishing mortality rate (referred to as the F_{ABC} value).

More formally, Amendment 56 of the Bering Sea and Aleutian Islands Groundfish Fisheries Management Plan (FMP), approved by the North Pacific Fishery Management Council (NPFMC) in June 1998, provides the following ABC and OFL guidelines for the groundfish fisheries.

Acceptable Biological Catch is a preliminary description of the acceptable harvest (or range of harvests) for a given stock or stock complex. Its derivation focuses on the status and dynamics of the stock, environmental conditions, other ecological factors, and prevailing technological characteristics of the fishery. The fishing mortality rate used to calculate ABC is capped as described under "overfishing" below.

Overfishing is defined as any amount of fishing in excess of a prescribed maximum allowable rate. This maximum allowable rate is prescribed through a set of six tiers, which are listed below in descending order of preference, corresponding to descending order of information availability. The Science and Statistical Committee (SSC) of the NPFMC will have final authority for determining whether a given item of information is reliable for the purpose of this definition, and may use either objective or subjective criteria in making such determinations. For tier (1), a pdf refers to a probability density function. For tiers (1–2), if a reliable pdf of B_{MSY} is available, the preferred point estimate of B_{MSY} is the geometric mean of its pdf. For tiers (1–5), if a reliable pdf of B is available, the preferred point estimate is the geometric mean of its pdf. For tiers (1–3), the coefficient *a* is set at a default value of 0.05, with the understanding that the SSC may establish a different value for a specific stock or stock complex as merited by the best available scientific information. For tiers (2–4), a designation of the form "$F_{X\%}$" refers to the *F* associated with an equilibrium level of spawning per recruit (SPR) equal to *X%* of the equilibrium level of spawning per recruit in the absence of any fishing. If reliable information sufficient to characterize the entire maturity schedule of a species is not available, the SSC may choose to view SPR calculations based on a knife-edge maturity assumption as reliable. For tier (3), the term $B_{40\%}$ refers to the long-term average biomass that would be expected under average recruitment and $F = F_{40\%}$.

The details of the tier specifications are given in NPFMC (2001). Essentially, the tier system is intended to provide a buffer between the overfishing level and the ABC level. One reason for this is that in season management measures change status depending on whether the ABC or OFL has been reached (e.g., a particular fishery will not open if bycatch of another species might exceed the other species OFL). Another feature of this system is that each stock is determined to be within a "tier" depending on the level of information available about that stock; i.e., if analyses are extensive and considered reliable by the SSC, then a higher tier might be applied in developing an ABC recommendation. For stocks where an assessment and/or data are limiting, a lower tier is used with a mechanism that will prevent rapid development of a new fishery without first having some formal analyses on the productivity of the stock (or in some cases, stock complex). These were designed with the precautionary approach in mind as outlined in Restrepo et al. (1998).

Sea Lion Issues.—Coincident with fishing activities are a number of ecosystem and environmental concerns. Prominent among these is the population recovery potential of the endangered western stock of Steller sea lions. NMFS and the NPFMC have made changes to the pollock fisheries in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA). These have been designed to reduce the possibility of competitive interactions with Steller sea lions. Comparisons of seasonal fishery catch and pollock biomass distributions (from surveys) by area in the EBS led to the conclusion that the pollock fishery had disproportionately high seasonal harvest rates within Steller sea lion critical habitat which *could* lead to reduced sea lion prey densities. Consequently, the management measures were designed to redistribute the fishery both temporally and spatially according to pollock biomass distributions. The underlying assumption in this approach was that the independently derived area-wide and annual exploitation rate for pollock would not reduce local prey densities for sea lions. These measures include: 1) Additional pollock fishery exclusion zones around sea lion rookery or haulout sites, 2) Reductions in the seasonal proportions of TAC that can be taken from critical habitat, and 3) Seasonal TAC releases to disperse the fishery in time.

Prior to the management measures, the pollock fishery occurred in each of the three major fishery management regions of the North Pacific Ocean managed by the NPFMC: the Aleutian Islands (1,001,780 km^2 inside the EEZ), the EBS (968,600 km^2), and the GOA (1,156,100 km^2). The marine portion of Steller sea lion critical habitat in Alaska west of 150°W encompasses 386,770 km^2 of ocean surface, or 12% of the fishery management regions.

Prior to 1999, a total of 84,100 km^2, or 22% of critical habitat, was closed to the pollock fishery. Most of this closure consisted of the 10 and 20 nm radius all-trawl fish-

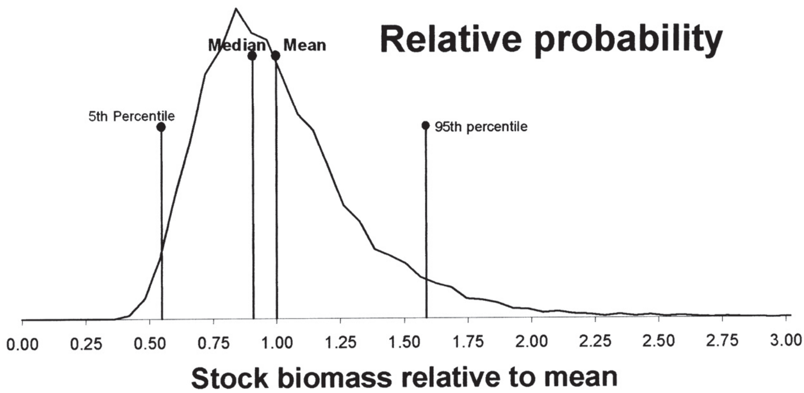

Figure 12. Relative probability of simulated spawning stock biomass relative to the mean (rescaled to equal 1.0) for an unfished stock. Note that slightly <5% of the time the stock will drop below 50% of the unfished biomass and than more than half of the time, the stock will be below the expected mean value of the stock.

ery exclusion zones around sea lion rookeries (48,920 km^2 or 13% of critical habitat). The remainder was due to the Bogoslof Island management area which represented 35,180 km^2, or 9% of critical habitat. The Bogoslof Island region has been closed pursuant to an international agreement to protect spawning stocks of central Bering Sea pollock.

In 1999, an additional 83,080 km^2 (21%) of critical habitat in the Aleutian Islands was closed to pollock fishing along with 43,170 km^2 (11%) around sea lion haulouts in the GOA and EBS. Consequently, a total of 210,350 km^2 (54%) of critical habitat was closed to the pollock fishery. The portion of critical habitat that remained open to the pollock fishery consisted primarily of the area between 10 and 20 nm from rookeries and haulouts in the GOA and parts of the EBS foraging area.

The Bering Sea/Aleutian Islands pollock fishery was also subject to changes in total catch and catch distribution due to other, non-sea lion related measures. For example, the AFA reduced the capacity of the catcher/processor fleet and permitted the formation of cooperatives in each industry sector. Both of these changes would be expected to reduce the rate at which the catcher processor sector (allocated 36% of the EBS pollock TAC) caught pollock beginning in 1999 and the fleet as a whole in 2000. Because of some of its provisions, the AFA gave the industry the ability to respond efficiently to changes mandated for sea lion conservation that otherwise could have been more disruptive to the industry.

Reductions in seasonal pollock catches from BSAI sea lion critical habitat were realized by closing the entire Aleutian Islands region to pollock fishing and by phased-in reductions in the proportions of seasonal TAC that could be caught from the Sea Lion Conservation Area, an area which overlaps considerably with sea lion critical habitat. In 1998, over 22,000 mt of pollock was caught in the Aleutian Island regions, with over 17,000 mt caught in AI critical habitat. Since that time directed fishery removals of pollock have been prohibited.

On the EBS shelf, both the catches of pollock and the proportion caught in critical habitat have been reduced significantly since 1998 as a result of the management measures (though the drop in the latter half of 2000 was due to closures from a court injunction).

Issues of Sustainability and Variability

The Alaska pollock resource of the EBS has population characteristics that have been well observed over the past three decades. One main characteristic of population is the effect of year-class variability (e.g., Fig. 7). This recruitment variability has had big impacts on the subsequent population variability. The question then is how this affects the long-term sustainability of the fishery. To address this issue a simulation model (with pollock-like characteristics) was developed to compare expected biomass variability with and without fishing. Additionally, a constant harvest rate policy was compared to the current scheme used where fishing mortality is given as a function of stock size as in Figure 11.

The simulations consisted of a 10,000 yr age-structured projection with 15 age-classes and estimates of natural mortality, mean weight-at-age, and selectivity as in Ianelli et al. (2001). Recruitment was modeled as log-normally distributed with a variance of $(0.9)^2$. The key output measure is spawning biomass since this is the primary metric on the status of the stock. Spawning biomass units were rescaled to have a mean value of 1.0 so that the relative probability could easily be evaluated. For simplicity, over the range of biomass values in the simulations, recruitment variability was assumed to far outweigh the impact of an underlying stock-recruitment relationship. That is, the spawning biomass levels had no effect on expected recruitment levels. While this assumption is clearly flawed, the purpose of this exercise is simply to expose the type of biomass variability that one might expect if similar recruitment patterns were observed.

Results and Summary

Results from the simulations show that stock variability in nature, even without fishing is moderate and that the median value is about 90% of the mean (Fig. 12). Adding the effect of fishing (at constant and adjusted rates) increases the variability somewhat and the median value to about 86% of the mean (Fig. 13). The current conservation regime for managing groundfish stocks adjusts the rates in an attempt to reduce the probability of lower stock levels, reducing the chance of having the stock drop below some minimum stock-size thresholds (e.g., 50% of the B_{msy} level). Clearly, the bottom panel of Figure 13 shows that the adjusted fishing mortality rate used by the NPFMC reduces the probability of dropping below the minimum stock-size threshold. Of course, the effect of adding an explicit stock-recruitment relationship would change the values of these probabilities. However, the relative difference between adjusted and constant fishing mortality rates would be very similar.

The pollock fishery currently appears to be reasonably sustainable. As more is learned about how environmental conditions affect the pollock resource and the ecosystem as a whole, the prospect for managing the fishery in a sustainable way is likely to increase. Sustainability is likely due primarily to early decisions on how the fishery was to be regulated. This included using truly effective quotas, which resulted in effective effort rationalization. Additionally, the overall 2-million t cap on catch of all groundfish species from the EBS and Aleutian Islands ecosystem has limited

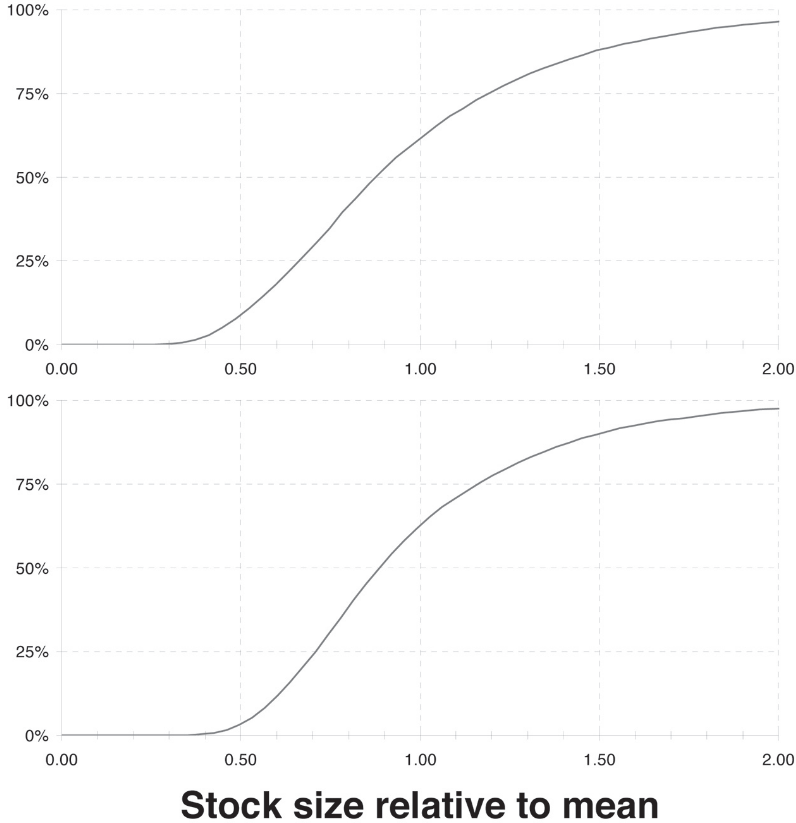

Figure 13. Cumulative probability of simulated spawning stock being lower than the mean (rescaled to equal 1.0) for a stock fished (top panel) at a constant (unadjusted) $F_{40\%}$ rate; and (bottom panel) at the adjusted $F_{40\%}$ by Amendment 56 rule given in Figure 11.

individual stock quotas. This has led to a stabilized fishery well within the bounds of sound conservation principals. Primary productivity sources for the EBS shelf appears to be high and relatively stable. This fortunate consequence, combined with a rational, science-based development of the pollock fishery (via succession from foreign to domestic fishing) appears to provide ideal conditions for sustaining the EBS pollock resource.

Literature Cited

Bailey, K. M., T. J. Quinn, P. Bentzen, and W. S. Grant. 1999. Population structure and dynamics of walleye pollock, *Theregra chalcogramma*. Adv. in Mar. Biol. 37: 179–255.

Clark, W. G. 1991. Groundfish exploitation rates based on life history parameters. Can. J. Fish. Aquat. Sci. 48: 734–750.

__________ and C. P. Archibald. 1982. A general theory for analyzing catch-at-age data. Can. J. Fish. Aquat. Sci. 39: 1195–1207.

Hiatt, T., R. Felthoven, and J. Terry. 2001. Stock assessment and fishery evaluation report for the groundfish fisheries of the Gulf of Alaska and Bering Sea/Aleutian Island area: economic status of the groundfish fisheries off Alaska, 2000. Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pac. Fish. Mgmt. Council, Anchorage. 99 p.

Ianelli, J. N. and D. A. Fournier. 1998. Alternative age-structured analyses of the NRC simulated stock assessment data. Pages 81–96 *in* V. R. Restrepo, ed. Analyses of simulated data sets in support of the NRC study on stock assessment methods. NOAA Tech. Memo. NMFS-F/SPO-30. 96 p.

__________, T. Buckley, T. Honkalehto, N. Williamson, and G. Walters. 2001. Bering Sea-Aleutian Islands Walleye Pollock Assessment for 2000. Pages 1–82 *in* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pac. Fish. Mgmt. Council, Anchorage. Section 1.

McAllister, M. K. and Ianelli, J. N. 1997. Bayesian stock assessment using catch-age data and the sampling-importance resampling algorithm. Can. J. Fish. Aquat. Sci. 54: 284–300.

Methot, R. D. 1990. Synthesis model: an adaptable framework for analysis of diverse stock assessment data. Pages 259–277 *in* L. Low, ed. Proc. Symp. on Applications of Stock Assessment Techniques to Gadids. Int. North Pac. Fish. Comm. Bull. 50.

NMFS. 1999. Our living oceans. Report on the status of U.S. living marine resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-41.

NPFMC. 2001. Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pac. Fish. Manag. Council, Anchorage.

Quinn, T. J. and R. B. Deriso 1999. Quantitative fish dynamics. Oxford University Press, New York. 542 p.

Restrepo, V. R., G. G. Thompson, P. M Mace, W. L. Gabriel, L. L. Low, A. D. MacCall, R. D. Methot, J. E. Powers, B. L. Taylor, P. R. Wade, and J. F. Witzig. 1998. Technical guidance on the use of precautionary approaches to implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act. NOAA Tech. Memo. NMFS-F/SPO-3 54 p. NMFS, Silver Spring.

Traynor J. J. and M. O. Nelson. 1985. Results of the U.S. hydroacoustic survey of pollock on the continental shelf and slope. Pages 192–199 *in* R. G. Bakkala and K. Wakabayashi, eds. Results of cooperative U.S.-Japan groundfish investigations in the Bering Sea during May–August 1979. Int. North Pac. Fish. Comm. Bull. 44.

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